

THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

VOL. 13

OCTOBER, 1928

NO. 10

DYSCRASITE AND THE SILVER-ANTIMONY CONSTITUTION DIAGRAM

G. M. SCHWARTZ, *University of Minnesota.*

INTRODUCTION

In connection with an investigation of certain silver ores it was found that etching tests on a lump of supposed native silver from Cobalt, Ontario, gave an excellent etch pattern which did not correspond to results of etching tests on native silver from other localities. The pattern may be obtained by treating with either HNO_3 , CuCl_2 , KCN , or KMnO_4 . Concentrated HCl will develop the pattern if left on for several minutes. The general nature of the intergrowths is similar to that identified by Van der Veen¹ as dyscrasite and native silver. The intergrowth is explained by him as due to a segregation from a solid solution. Inasmuch as the system silver-antimony has been investigated it seemed desirable to make some comparisons of data on natural dyscrasites with data developed by studies of the silver-antimony constitution diagram.

THE SILVER-ANTIMONY CONSTITUTION DIAGRAM

The silver-antimony constitution diagram has been investigated in detail by Petrenko² and by Liebisch², although several workers had previously worked on parts of the diagram. Guertler³ gives a summary of the work on the system and a graph showing the probable diagram. According to the diagram (see Fig. 1) neither silver nor antimony form as a pure solid from a melt containing both metals. Silver will contain antimony in solid solution up to about 10 per cent by weight. Antimony will hold about 5 per cent of silver in solution at temperatures below 485°C . When

¹ Van der Veen, R. W., *Mineralography and Ore Deposition*, The Hague, 1925, figure 111.

² Petrenko, G. J., *Zeit. anorg. chem.*, Vol. 50, p. 133, 1906. Liebisch, T., *Monatsber.*, Berliner A. K., p. 365, 1910.

³ Guertler, W., *Metallographie, Berlin*, Vol. 1, 1912, p. 769.

the composition of a mixture of the two metals lies between 25 and 35 per cent antimony with 75 to 67 per cent silver, an intermetallic compound Ag_3Sb exists for low temperatures. This intermetallic compound has the composition of the natural mineral dyscrasite. As has been noted by Rastall⁴, dyscrasite may form at 560° by a reaction between the solid solution of antimony

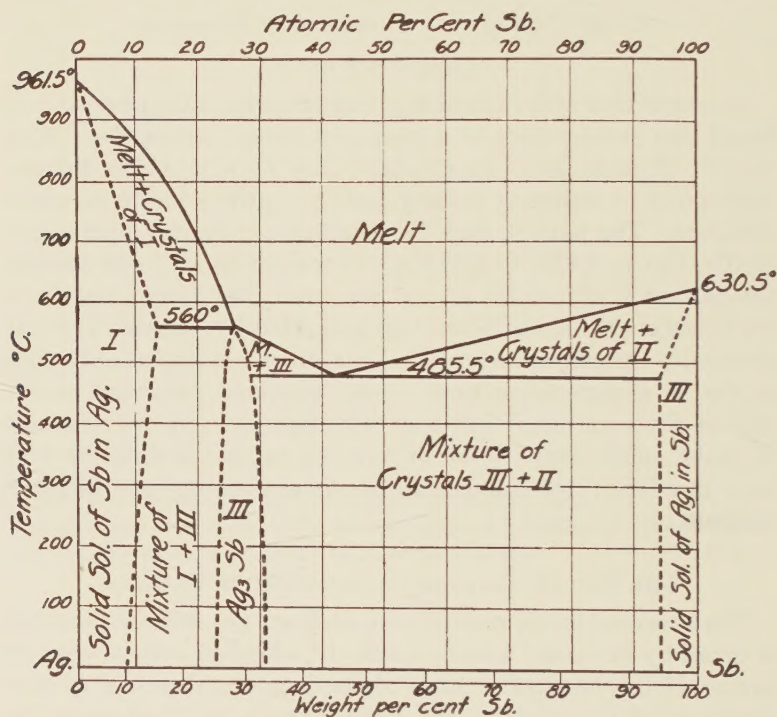


FIG. 1. Silver-Antimony Constitution Diagram. From Guertler, Metallographie, Vol. 1, page 769.

in silver and the fused liquid. If the system contains less than 25 per cent and more than 10 per cent antimony, dyscrasite will be formed accompanied by the solid solution $\text{Ag}+\text{Sb}$. The dyscrasite forms at 560°C . whereas the silver solid solution forms between 560° and 961°C . If the weight per cent of antimony is greater than 33, dyscrasite will be accompanied by the solid solution

⁴ Rastall, R. H., *Geology of the Metalliferous Deposits*, Cambridge, 1925, p. 225.

Sb+Ag. In this case the temperature of formation of dyscrasite is 485.5°C., the eutectic temperature. The eutectic composition is about 45.5 per cent by weight of antimony and 54.5 per cent by weight of silver, or 41.5 atomic per cent antimony and 58.5 atomic per cent silver.

So far as the writer is aware the known minerals are limited to the silver side of the diagram, that is, mainly from the intermetallic compound Ag_3Sb to pure silver.

APPLICATION OF DATA TO VEINS

In attempting to apply the data available in the constitution diagram shown in Figure 1, the point that at once presents itself is that the Cobalt deposits could scarcely have been deposited as a melt. There is, of course, no necessity for distinguishing between a melt and a solution and it may be accepted that the Cobalt veins were deposited by solutions. If the solutions were of such a nature that the silver and antimony in ratio of 89 to 11 would crystallize out at, for example, 300°C. then a solid solution would probably form. At least we have no very good reason to suppose that it would not. As this solid solution cooled it would become saturated with Ag_3Sb which would precipitate out. Of this we may be certain if the diagram given by Guertler is correct. It may be argued that the presence of water which probably is the main constituent of the depositing solution introduces a new phase and, therefore, the binary constitution diagram does not hold good. This is doubtless true as long as the antimony and silver are in water solution, but on precipitation the water phase is excluded and the antimony-silver equilibrium holds. If the two elements were deposited as separate phases at elevated temperatures they would soon form a solid solution if that were the stable phase at the temperature existing. This point is one of the utmost importance in considering ore minerals which are believed to be precipitated from fairly complex solutions. It enables us to utilize part of the work which has been so laboriously done by the physical chemists and metallographers. The limitations of the possibilities must, however, be clearly recognized.

SILVER-DYSCRASITE INTERGROWTH FROM COBALT, ONTARIO

Dyscrasite has long been known as a constituent of the ores in the Cobalt district. That it occurred as an intergrowth with silver

was noted by Ellsworth⁵. Analyses showed too small amounts of antimony to form theoretical dyscrasite and a microphotograph shows skeleton crystals of dyscrasite in native silver.

The significance of the occurrence of varying amounts of antimony in the silver from this region was recognized by Walker⁶ who gives several analyses. Walker states, "From information available it seems probable that the material commonly called dyscrasite is made up of a eutectic intergrowth of silver and an antimonide of silver, probably Ag_3Sb , which should contain 27.1 per cent of antimony."

The specimen labelled "native silver" from which the intergrowths here described were obtained was an irregularly rounded mass about four centimeters in diameter. It contained some intergrown calcite, but otherwise seemed fairly pure. It was sawed in two, polished, and smaller pieces sawed off later for analysis and experimental purposes. Previous to etching the polished surface shows a brilliant mirror surface when freshly polished, but faint outlines of the intergrowth may be seen at places. All parts polished thus far show the intergrowths on etching. It was difficult to identify the constituents of the intergrowth found in the specimen described. Following the determinative tables of either Murdoch or Davy and Farnum it would seem that the blades were native silver and the groundmass dyscrasite. From the illustrations by Ellsworth, Walker, and Van der Veen⁷ it is obvious that they have identified the blades as dyscrasite and the groundmass as silver. This would accord with results predicted from the constitution diagram. The groundmass is probably a solid-solution of antimony in silver, as noted above.

Microchemical tests on polished surfaces gave the following results:

	DYSCRASITE BLADES	SILVER GROUNDMASS
HNO_3 (1-1)	Iridescent-brownish	Darkens
HCl (1-1)	Negative	Negative
HCl (con.)	Negative	Tarnishes brown very slowly
KCN (20%)	Negative	Tarnishes brown slowly
FeCl_3 (20%)	Iridescent	Iridescent
KOH (sat.)	Negative	Negative
HgCl_2 (sat.)	Tarnished yellow-brown	Brown to iridescent

⁵ Ellsworth, H. V., *Report Ont. Bureau of Mines*, Vol. 25, pt. 1, p. 203, 1916.

⁶ Walker, T. L., Dyscrasite from Cobalt, Ontario. *Univ. of Toronto Studies, Contr. to Canadian Mineralogy*, No. 12, pp 20-22, 1921.

⁷ *Op. cit.*

Figures 2, 3, and 4 show characteristic intergrowths. The intergrowths are not unlike others which have been attributed to segregation from a solid solution⁸. This suggested the possibility

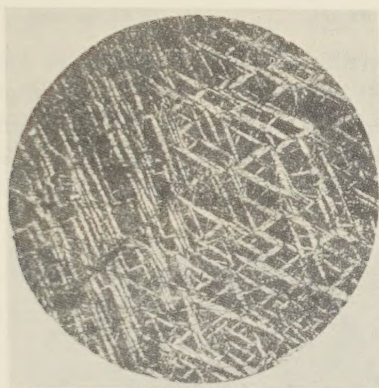


FIG. 2. Photomicrograph showing native silver, or solid solution Ag + Sb (dark), containing blades and lattice of dyscrasite (light). Etched. Cobalt, Ontario. Mag. X. 18.



FIG. 3. Field of same surface as Fig. 2, more highly magnified. Mag. X55.

of correlating the intergrowths with the constitution diagram. A partial analysis of a typical piece of the specimen cut off with a diamond saw gave the following results. The writer is indebted

⁸ Schneiderhöhn, H., *Untersuchung von Erzen*, Berlin, 1922, Van der Veen, F. W., *op. cit.* Schwartz, G. M., Intergrowths of Chalcopyrite and Cubanite, *Economic Geology*. Vol. 22, pp. 44-61, 1927.

to the University of Minnesota Mines Experiment Station for the analysis.

Silver.....	81.67 per cent
Antimony.....	10.32 per cent
Arsenic.....	0.44 per cent

The impurity is mainly calcite. If the silver and antimony are recalculated to 100 per cent the results are: silver, 88.78 per cent antimony 11.22 per cent. It is probable that arsenic atoms would substitute for antimony in which event the percentages would be: silver, 88.25 per cent, and antimony plus arsenic, 11.75 per cent.

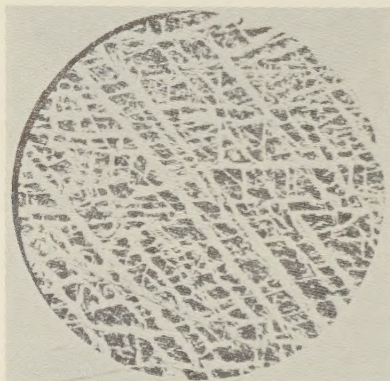


FIG. 4. Intergrowth of slightly different type than that shown in Figs. 2 and 3. Dyscrasite (light) as a more continuous network. Etched and repolished. Cobalt, Ontario. Mag. X 55.

Referring now to Fig. 1, it may be observed that in the case of a melt of either of the above compositions a solid solution of silver and antimony would form when the melt completely solidifies at $560^{\circ}\text{C}.$, but as cooling progressed the solid solution would break down due, it is apparent, to saturation of the solid solution with Ag_3Sb , which would precipitate out. For eleven per cent antimony the temperature of the break-down would be about $250^{\circ}\text{C}.$ It should be noted that the boundaries of the various components are dotted, indicating that they are not accurately determined, but represent the probable diagram. It might be logically inferred that the Cobalt native silver-dyscrasite was deposited at a temperature of $250^{\circ}\text{C}.$, or higher. The fact that the line separating the two states of equilibrium makes the exact temperature of the breakdown rather uncertain.

EXPERIMENTAL DATA

If the specimen described above represents a mixture of Ag_3Sb and the solid solution ($\text{Ag} + \text{Sb}$) which has formed by the breaking down of a solid solution during cooling, it should form a solid solution on heating. A small piece was sawed off, polished, and etched to observe the intergrowth. This was sealed in a pyrex tube and heated at 500°C . for three hours and then quenched. Microscopic examination and etching tests fail to give any evidence of the original intergrowth. The specimen appeared perfectly homogeneous and had the appearance of native silver in most respects.

The specimen was reheated and slowly cooled at varying rates, but thus far the two phases have not been reprecipitated in a recognizable form. Possibly extremely slow cooling is necessary or possibly some antimony was volatilized at the higher temperatures. A slight deposit was noted on the tube used for the first test, but this did not appear in later experiments. A small reduction in the antimony present would be sufficient to prevent saturation with Ag_3Sb .

COMPOSITION OF DYSCRASITE

Dyscrasite has been described as of an extremely variable composition, ranging from Ag_2Sb to Ag_{18}Sb . Dana⁹ summarizes the data on composition showing a wide variation. Two of the analyses quoted in the sixth edition agree with Ag_3Sb . A greater number of analyses are given in the 5th edition.

In a more recent paper Smith¹⁰ describes the occurrence of large masses of dyscrasite at the Consols Mine, Broken Hill. He gives the most common types as Ag_3Sb and Ag_6Sb , followed by Ag_4Sb , Ag_5Sb , Ag_9Sb , Ag_{12}Sb , and Ag_{18}Sb .

Doelter¹¹ gives a more extended summary of the composition and quotes many analyses and concludes that Ag_3Sb is the most common and that dyscrasite is often a solid solution of silver in Ag_3Sb . The constitution diagram shown by Guertler indicates, however, that the so-called dyscrasite is a physical mixture of true dyscrasite, Ag_3Sb , and the solid solution ($\text{Ag} + \text{Sb}$).

⁹ Dana, System of Mineralogy, 1911, 6th Ed., p. 43; also 5th. Ed., p. 35.

¹⁰ Smith, George, On the Occurrence of Dyscrasite in Australia. *Am. J. Sc.*, Vol. 49, pp. 278-280, 1920.

¹¹ Doelter, C., Handbuch der Mineralchemie, Band IV, 234-238, 1926.

The Cobalt specimen described above appears homogeneous at first sight even on the polished surface, unless it is etched. The analysis would indicate a formula of Ag_3Sb , but etching and microscopic examination show that it is in reality composed of two phases. One of these corresponds to native silver, the other to dyscrasite.

From a consideration of the constitution diagram of silver and antimony it seems quite probable that the variable composition reported for dyscrasite is due to an intergrowth of the intermetallic compound Ag_3Sb with the silver-antimony solid solution, or antimony-silver solid solution in the case of Ag_2Sb . The formula for pure dyscrasite existing as a single homogeneous phase is evidently Ag_3Sb .

SIGNIFICANCE OF DYSCRASITE

Dyscrasite has been described as both a hypogene and as a supergene mineral. At Cobalt, for example, perhaps all would agree that it is primary. Whitehead¹² describes its occurrences at Chañarcillo, Chile, where it is supergene. It is probably significant that no intergrowths were described by Whitehead. If they are formed as suggested above they would not occur in ores deposited by cold waters. Further data are necessary to be certain, but it appears probable that supergene dyscrasite would not show crystallographic intergrowths of the type described above. If intergrowths are found they would seem to indicate deposition at temperatures ranging up to 560°C . and a breaking down on cooling. The presence of intergrowths would be a criterion indicating hypogene deposits. Their absence would have no necessary significance, but would indicate supergene origin as one of the possibilities.

CONCLUSIONS

1. It is concluded that the formula of dyscrasite is Ag_3Sb , which is also known as an intermetallic compound in the system Ag-Sb . Dyscrasite with this formula should be homogeneous.

2. Compositions other than Ag_3Sb are due to: (a) the solid solution of antimony in silver (0-10% Sb), (b) a mixture of Ag_3Sb and the solid solution (alloy) of antimony in silver (10-26% Sb), (c) a mixture of Ag_3Sb and the solid solution of silver in antimony (33-95% Sb).

¹² Whitehead, W. L., The Veins of Chañarcillo, Chile, *Ec. Geol.*, Vol. 14, pp. 1-45, 1919.

3. A solid solution of 0-5% of silver in antimony has been produced artificially, but is not known as a mineral.

4. Mixtures of Ag_3Sb and the solid solution $\text{Ag} + \text{Sb}$ occur as crystallographic intergrowths, as illustrated by the photomicrographs.

5. An intergrowth such as is shown to exist in the ores from Cobalt, Ontario, may originate by (a) the crystallization of the solid solution ($\text{Ag} + \text{Sb}$) above $560^\circ\text{C}.$, and the crystallization of Ag_3Sb at $560^\circ\text{C}.$; (b) the formation of the solid solution ($\text{Ag} + \text{Sb}$) in the narrow range of 10 to 15% Sb and its breakdown into ($\text{Ag} + \text{Sb}$) and Ag_3Sb on cooling.

6. The wide range in analyses of so-called dyscrasite is inferred to be due to mixtures of the type described, which may be recognized only by etching the polished surfaces and examination under the microscope.

THE DOUBLE DISPERSION METHOD OF MINERAL DETERMINATION¹

(PRELIMINARY PAPER)

R. C. EMMONS, *University of Wisconsin.*

During the past two or three years the writer has conducted a series of experiments and collected data with the aim of improving the methods commonly used to determine minerals in the laboratory by means of the petrographic microscope. Attention was directed to two principal considerations. First, the index of minerals for light of the wave length of the sodium line can profitably be determined correctly to the third decimal place instead of within the limits expressed commonly by $\pm .005$. This greater accuracy is required by the greater detail with which minerals are becoming known and also by the realization of the importance of small variations in refractive index, especially with regard to their bearing on differences in chemical composition as brought out by the work of A. N. Winchell and others². Second, it was hoped to increase the speed of an accurate study of the optical properties of a given mineral specimen. It is felt that some degree of success has been attained along both these lines, especially since even students with a preliminary training of two to four hours a week during one college semester, are able to determine the index N_D of the ordinary ray of quartz consistently with an error of $\pm .0002$ and the entire determination requires fifteen minutes to half an hour, depending upon the student. It is felt, therefore, that others may be interested in the details of the procedure which are nearing completion as conceived by the writer. An early note was published³ when it was first thought that temperature change and wave length change could both be used beneficially, but at that time neither this degree of accuracy was hoped for nor was it believed that the time required could be reduced to such an extent. It was thought at that time that the main benefit lay in being able to determine more than one index of a mineral grain of moderate

¹ The diagrams and subject matter of this paper have been given to Dr. A. N. Winchell for incorporation in the revised edition of his "Optical Mineralogy," Part I.

² A. N. Winchell, *Optical Mineralogy*, Part II, Numerous references to this subject in the literature are given throughout the text.

³ A. N. Winchell and R. C. Emmons, Some Methods for Determining Refractive Indices. *Am. Mineral.*, Vol. 11, 1926, p. 115.

birefringence. Equal or greater emphasis is now placed on accuracy, speed, and the determination of the specific dispersion of minerals which is doubtless to receive progressively more attention in the future. The following notes and diagrams are offered in the hope that others may benefit by the information which they contain.

The methods of mineral determination commonly followed, employ the use of white light, which is to say light of all visible wave lengths ranging possibly from 4500Å to 7000Å. The sum total of white light is generally conceded to be equivalent to light of the wave length of the sodium flame, that is 5893Å. It is a common experience, in determining the refractive index of a properly oriented grain which should yield but one value, to observe two Becke lines or two illuminated sides of grains, according to the method employed. One of these lines or edges is blue and the other is yellowish red. They denote divergent indices. If such a grain be tested with light of one wave length (i. e. monochromatic light)⁴ it will be found that for a particular wave length the grain disappears entirely, that is, yields no Becke line or illuminated edge, and for shorter wave lengths the grain is lower in index than the liquid, and for longer wave lengths the grain is higher in index than the liquid. The refractive index of a substance increases with decrease in the wave length of light being transmitted, and *vice versa*, the refractive index decreases with increase in the wave length of light. This property of substances is known as their chromatic dispersion and is a characteristic property. Further, it may be commonly observed that this increase or decrease in refractive index is less pronounced in the denser media, though this rule is by no means universal. But in general the dispersion of liquids is greater than that of solids, and though the dispersion of solids normally increases with their refractive index, the dispersion of liquids increases even more with refractive index. Further, amongst liquids there is a great difference in dispersive power. It is obvious then, that if a mineral grain is immersed in a liquid the refractive index of which is near that of the mineral, then by changing the wave length of light used, it should be possible, within certain limits, to change the index of the liquid to match that of the mineral. And the limits imposed by

⁴ H. E. Merwin first used the dispersion of liquids in a practical way to determine N_D for minerals. M. Tsuboi elaborated his method, *Mineralogical Magazine*, Vol. XX, p. 108.

the liquid will be widened if the wave length dispersion of the liquid is high. To this end, therefore, a diligent search was made for liquids of high wave length dispersion, but in making the search detailed attention was paid to still another factor.

The refractive index of the liquid depends also upon the temperature of the liquid, decreasing with increase in temperature, and increasing with decrease in temperature. In fact, so important is this that modern refractometers are equipped with water circulation cells, the purpose of which is to maintain a controlled temperature for the liquid being measured. Although the thermal dispersion of liquids is comparatively high, yet that of minerals is, with very few exceptions, very low, being recorded in only the fifth or sixth place of decimals. There is available then, another means by which the index of a liquid may be changed to match that of a mineral grain within limits imposed by the thermal dispersion of the liquid.

By considering, then, in the search for new liquids, not only the wave length dispersion, but also the thermal dispersion, there was selected first, a set of 13 liquids, the index range of which extends from 1.40 to 1.78 without a single interruption, and usually with considerable overlap. This set covers a slightly greater range than the set of 60 liquids normally used and it enables the student to determine the refractive index to a correct figure instead of between the figures of two available liquids. Also, by eliminating the necessity of changing mounts so frequently, it reduces the required time for a determination very considerably.

In a great deal of work which the petrographer does the minerals on which interest centers are so commonly present in very small amounts that a grain once found should not be lost. Some petrographers recommend that a particular grain be transferred from one liquid to another but personally I have neither the ability nor patience required to do this, especially if the grain is small, and in any case I do not recommend it lest some of the first liquid adhere to the grain when it is immersed in the second liquid. It is, therefore, a keen satisfaction to the student to be able to work within a refractive index range on each mount instead of at a particular value. The increased accuracy which accrues from the use of this procedure is considerable as will be shown. And since the index of the immersion medium can be changed it is therefore possible, normally, after determining one index to rotate the grain

90° and to determine the other index. This becomes impossible for minerals of high birefringence, or if the higher index is at the lower end of the range of a chosen liquid and vice versa.

The most critical and most commonly recorded refractive index of minerals is that obtained for sodium light. But obviously it is seldom that the index of the liquid and that of the mineral coincide for light of this wave length. And since it is necessary to translate indices for light of other wave lengths into that for sodium, H. E. Merwin recommended that the index of the mineral should be determined for two or preferably three wave lengths by immersing the mineral successively in two or three liquids. If now the wave length of the light used is changed, causing a change in the refractive index of the liquid (and to a less extent of the mineral) and then the temperature of the mount is changed to bring about the opposite change in refractive index we have the mineral and liquid again matching in index. In other words we have accomplished all that we could have accomplished by transferring the particular grain being studied from one liquid to another, and by placing it in the exact orientation that it originally had. The actual procedure consists in changing the index of the liquid by a temperature change first and then changing the index back again by a change in the wave length. This is done because of the greater ease and speed of changing wave length. This may be done conveniently and rapidly as often as desired though three times at suitable intervals is sufficient. Three determinations suffice to give us the curve of dispersion of the mineral. Since the dispersion of minerals is not a straight line, two determinations are not enough for accurate work. By drawing the mineral curve, then, through the three points determined, the index of the mineral for sodium light may be read quite easily, or, for that matter, the index for light of any other wave length. A typical curve is shown in Figure 1.

The apparatus which the writer has employed in doing double dispersion work consists of a standard petrographic microscope on the stage of which fits a movable cell (Figure 2), through which water flows between two glass windows the lower one of which is thick, and the upper one of which is thin, to cut down insulation. The mount is made in the normal way upon the upper glass window. The path of light is from the lower nicol through the lower window, then through a thin layer of water, and through

the upper window and mount to the objective. Water of a controlled and variable temperature circulates through the cell thereby giving the desired control in temperature of the mount. The same water flows from the cell through an Abbe refracto-

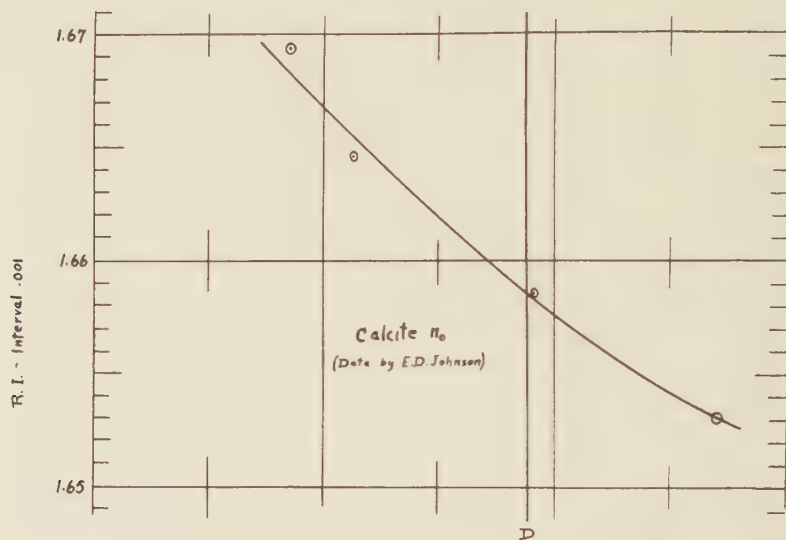


FIG. 1. Blank graphs of this type are kept in the laboratory.

meter on which is mounted the same liquid used in the mineral mount. A water heated and cooled cell is preferred to an electrically heated stage for these reasons: it gives an accurately

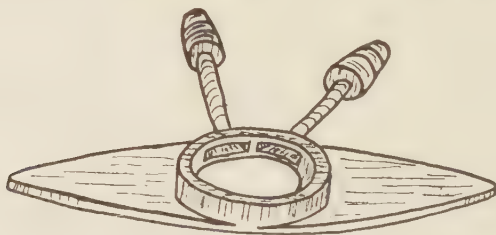


FIG. 2. Water circulation cell for the stage of the microscope.

identical temperature on the mount and the refractometer; it gives simplicity since the water circulation is required in any case for the refractometer; it gives more rapid and much lower cooling than an electric stage.

Two thermometers, which have been previously checked against each other are included in the system, one before the microscope cell, the other after the refractometer. When the thermometers agree within reasonable limits, then the index of the liquid on the microscope stage may be read directly on the refractometer at the same temperature. Next, the source of monochromatic light may be any standard monochromator having a constant deviation prism. The standard small Leitz monochromator illuminated by a Leitz Lilliput automatic arc has been found satisfactory. Bausch & Lomb makes a larger monochromator which is direct reading and gives more light. It is preferable to the Leitz, but costs slightly more. The Bausch & Lomb monochromator is being modified in minor details at the writer's request to make it more readily adaptable to microscope illumination for this purpose. The beam from a monochromator is focused on the mirror of the microscope, and this in turn adjusted in the ordinary way. When by proper manipulation an index of the mineral is made to coincide with that of a liquid, then the mirror of the microscope is tilted to project the monochromatic beam on to the mirror of the refractometer, and the refractometer is read, using the same wave length of light as was used on the mount. Abbe refractometers, however, do not read directly except for sodium light. A correction curve or tables⁵ may be obtained from the manufacturers by which each reading may be modified by simple addition or subtraction giving the correct value. The attempt is being made to have the manufacturers modify an Abbe refractometer by adding a second fine adjustment, the purpose of which will be to correct the error introduced by the use of monochromatic light. The instrument should then read directly.

The procedure employed then may be summarized. First, the unknown may profitably be studied very briefly in the ordinary way using liquids of three or four indices if necessary in order to locate very roughly on the refractive index scale the mineral or minerals of particular interest. Then using the curves provided

⁵ There is some question of the correctness of a curve to the fourth place of decimals. This does not affect the accuracy of the reading for sodium light as obtained from the plotted curve though it does to this extent affect the original readings for light of other wavelengths. The degree of possible error is greatest in the violet and at higher indices. It seldom affects more than the fourth place. It is not a consistent error.

in Figure 3 which show the "double dispersion" liquids on the refractive index scale, the proper liquid may be selected and a mount made. At the same time place a few drops of this liquid

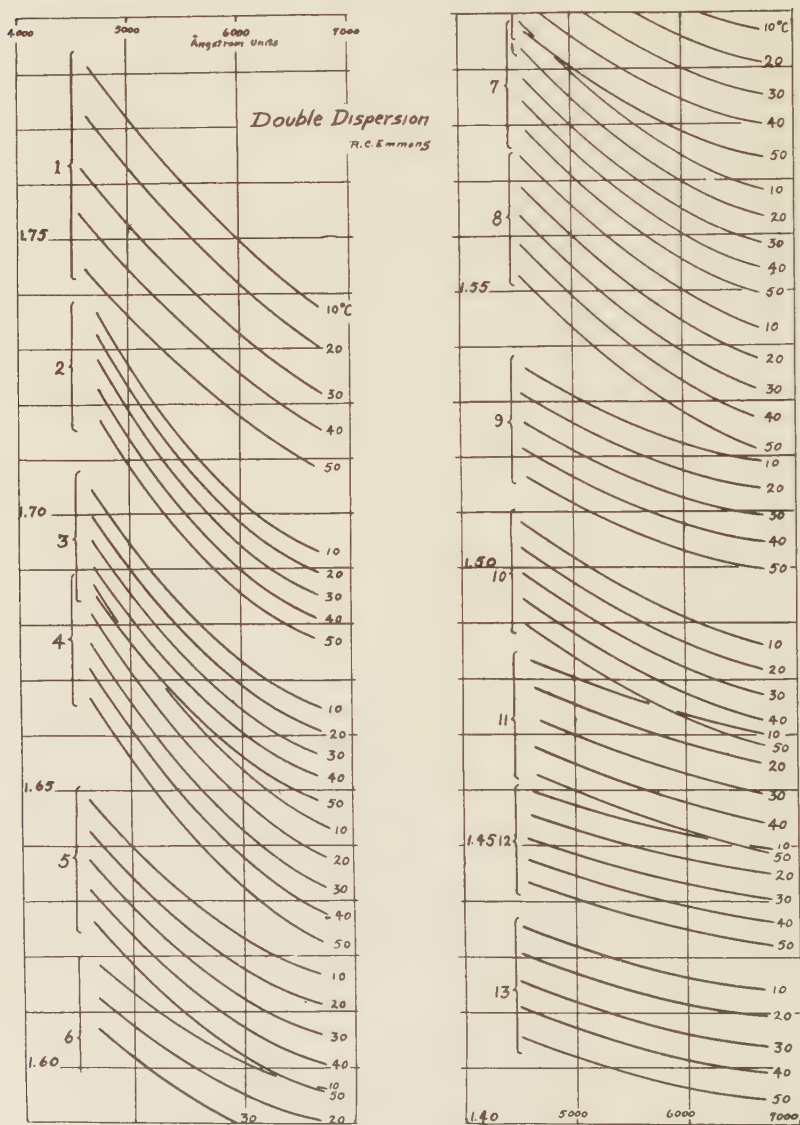


FIG. 3. Graphical representations of some of the optical properties of the liquids recommended for double dispersion use.

on the refractometer, turn on the water circulation, bringing the refractometer and the cell to the same temperature. Select a suitable grain and by adjusting the monochromator the index of this grain and that of the liquid can usually be made to agree. Read and record the temperature, the monochromator reading, and the refractometer reading, (making sure that the Amici dispersion prisms of the refractometer are set at 30 which is the neutral position proper for monochromatic light). Now change the temperature a few degrees, and adjust the monochromator to make the indices match again, and record the readings. Change the temperature once more and adjust as before. There are now available data for three correct refractive index readings on one ray. From the curve which these give the reading for light of the sodium wave length may be obtained. Also from this curve the dispersion $N_F - N_C$ for this ray of the mineral may be read. If the first selected grain is an optic axis grain then the index is N_c or β . Next a grain of maximum birefringence may be selected and N_o determined or N_o and N_p .

In studying grains of very high birefringence it will be found necessary to use more than one liquid medium and so also if the mean index of the grain is near the limit of the range of the liquid being used. But this limitation is overcome to some extent by the fact that the liquids at their limits overlap considerably. In general practice it is recommended that the graphs of the liquids be kept in front of the student as it facilitates the selection of the liquid to be used.

The liquids listed are single compounds (not solutions) for the double dispersion set and mostly so for the single dispersion set. They cannot, therefore, change in physical constants and may be relied upon regardless of exposure or heating. Those which are mixtures are carefully selected on the basis of volatility. They must, however, be checked periodically. One mixture may be substituted in the double dispersion set to reduce cost as suggested in the table.

The first set of thirteen liquids the writer has termed the double dispersion set on the basis of the two types of dispersion employed in their use. One liquid, however, such as barium mercuric iodide solution, of high refractive index and high dispersion may profitably be included in the set, since it raises the available scale from 1.78 to 1.85, but it must be used with great caution as its

refractive index is dependent upon its concentration, and the concentration may vary with evaporation.

The second set of liquids the writer has termed the single dispersion set (Figure 4). It consists of 20 liquids most of which are

1.76 *Single Dispersion*

1.77

1.76

1.75

1.74

1.73

1.72

1.71

1.70

1.69

1.68

1.67

1.66

1.65

1.64

1.63

1.62

1.61

Degrees Centigrade

10 14 18 22 26 30 34 38 42 46 50

1

2

3

4

5

6

7

8

1.60

1.59

1.58

1.57

1.56

1.55

1.54

1.53

1.52

1.51

1.50

1.49

1.48

1.47

1.46

1.45

1.44

1.43

1.42

1.41

1.40

9

10

11

12

13

14

15

16

17

18

19

20

10 14 18 22 26 30 34 38 42 46 50

FIG. 4. Single dispersion liquids to be used for temperature change only.

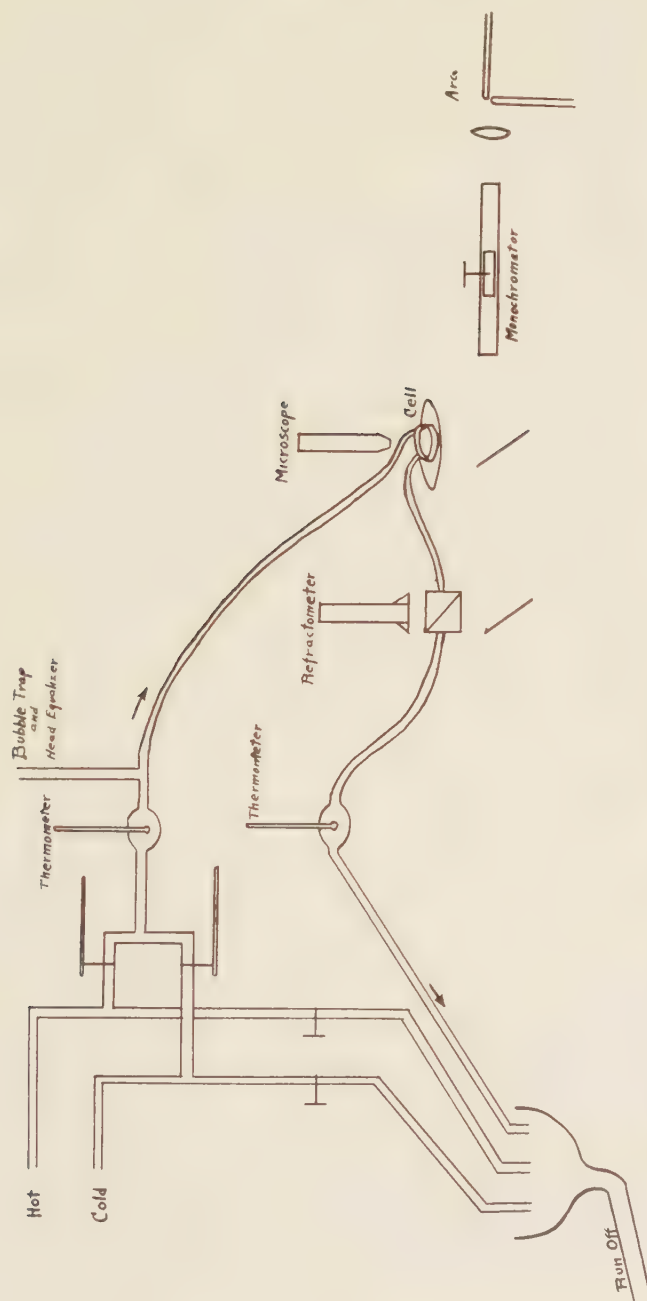


FIG. 5. General set-up of apparatus for double dispersion work. For single dispersion work a gas flame with sodium chloride in it is substituted for the monochromator and in the absence of a refractometer the curves of figure 4 may be used.

single compounds, but two are carefully selected mixtures, of approximately equal volatility used to fill gaps when suitable liquids of single composition could not be found. This set is intended for use in laboratories not equipped with a monochromator. The apparatus for temperature control may be built easily, and salts whose flames give standard wave lengths are always available. These liquids have high thermal dispersion.

In the selection and manipulation of these liquids, Dr. C. W. Muehlberger⁶, a qualified chemist, was untiring in his assistance. Without his advice the selection would not have been possible.

The general set-up of the apparatus is shown in Figure 5. The design of cell has been perfected by Mr. J. S. Hipple⁷ who has made several models of different types in an attempt to get rid of the trapped air bubbles. The design now employed is quite good. Three cells are desirable in stock since the cover-glass windows are easily broken. These windows are cemented in by Canada balsam. The water valves used are standard main shut-off valves with the standard cones replaced by others having a narrow diamond shaped opening to give delicate control. These work very well indeed. In order to have hot and cold water at the control valves a constant overflow is maintained while working. All the work is conducted in a dark room.

Mr. W. B. Rayton of the optical division of the Bausch & Lomb Optical Co., has agreed to make all the parts necessary and the company will sell the entire set-up as a unit.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge his indebtedness for advice and suggestions to Dr. C. W. Muehlberger and Dr. A. N. Winchell.

TABLE I. DOUBLE DISPERSION LIQUIDS

LIQUIDS	N_D
1. Methylene Iodide	1.742.....24°C
2. α -Iodonaphthalene	1.697.....27
3. α -Bromonaphthalene + Dibromonaphthalene	1.668 (variable)
3a O-Bromiodobenzene (to replace No. 3 and 4)	1.660.....28
4. Phenylisothiocyanate	1.646.....27
5. Iodobenzene	1.616.....27

⁶ Dr. C. W. Muehlberger, Service Memorial Institute, Madison, Wisconsin, has kindly consented to make, purify and sell these liquids in sets until someone qualified can be found who is interested.

⁷ Mr. J. S. Hipple, Service Memorial Institute, Madison, Wisconsin, has agreed to make these cells for general use.

6. Bromoform	1.592.....27
7. O-Toluidine	1.568.....27
8. O-Nitrotoluene	1.543.....27
9. Propylene Bromide	1.515.....27
10. Methyl furoate	1.484.....26
11. Methyl thiocyanate	1.467.....24
12. Trimethylene chloride	1.445.....26
13. Ethyl monochloroacetate	1.419.....26

Complete physical constants will be supplied in a later paper. The writer has given a tentative list of values more complete than this list to A. N. Winchell for publication in his *Optical Mineralogy*, Part I, Revised edition.

TABLE II. SINGLE DISPERSION LIQUIDS

LIQUIDS	N_D
1. Methylene iodide	1.742.....24°C
2. Methylene iodide+Iodobenzene	1.715 (variable)
3. α -Iodonaphthalene	1.697.....27
4. α -Iodonaphthalene+ α -Bromonaphthalene	1.6770 (variable)
5. O-Bromiodobenzene (or α -Bromonaphthalene+Dibromonaphthalene)	1.660.....28 Do (variable)
6. Phenylisothiocyanate	1.646.....27
7. S-Tetrabromoethane	1.6344.....24
8. Iodobenzene	1.616.....27
9. Bromoform	1.592.....27
10. Anilin	1.581.....24
11. O-Toluidine	1.568.....27
12. O-Nitrobenzene	1.551.....24
13. Ethylene Bromide	1.536.....24
14. Propylene Bromide	1.515.....27
15. Pentachloroethane	1.508.....24
16. Methyl furoate	1.484.....26
17. Methyl thiocyanate	1.4669.....24
18. Isoamylsulphide	1.451.....24
19. Ethyl dichloroacetate	1.4350.....24
20. Ethyl monochloroacetate	1.4200.....24

Since two (or three) of these liquids are mixtures they must be used with some degree of caution and checked periodically as are standard immersion liquids.

Liquid number 6 of Table I (number 9 of Table II) is a low boiling liquid with high volatility. It is hoped to be able to replace it when a suitable substitute is found. It is used here because of its very high thermal dispersion. At high temperatures it is necessary to add it periodically to the mount.

The iodides in the higher ranges of index are apt to become discolored by the liberation of iodine. The color may be removed quite well by adding an aqueous solution of sodium carbonate and shaking thoroughly. Dr. Muehlberger recommends this procedure.

ANTHRAXOLITE FROM THE NORTHWEST
TERRITORIES OF CANADARALPH L. RUTHERFORD, *University of Alberta.*

During the summer of 1927 Mr. W. J. Dean, a student at the University of Alberta, was engaged by a prospecting party in the vicinity of Great Slave lake in the District of Mackenzie, Canada. Among the specimens which he collected from the Precambrian rocks were some pieces of a black, shiny material. These have an appearance strikingly similar to our museum specimen of anthraxolite from the Sudbury district in Ontario. The term *anthraxolite* was first used by Chapman as a name for coal-like solids which are the end products of metamorphism of petroleum.¹

The Sudbury anthraxolite was first described by Dr. Coleman over thirty years ago.² Since then several investigators at different times have reported the occurrence of coal in the Precambrian rocks of the Sudbury district. Coleman, in a recent article,³ has drawn attention to this so-called coal, maintaining it to be the same material as he originally described as anthraxolite. His description of the Sudbury anthraxolite applies equally well to the material which the writer has on hand.

The anthraxolite from Great Slave lake is brittle and black in color and is lustrous on a fresh surface. At first inspection it may appear metallic, due to the lustre and also to the prevalence of cubical outlines which are commonly present. On closer examination these are found to be fracture surfaces. These cube-like particles are on the average less than one-half inch in diameter. When heated in a Bunsen flame the particles decrepitate.

Coleman states that the Sudbury anthraxolite occurs as a vein associated with quartz and a little pyrite. The specimens collected by Mr. Dean all show vein quartz as a common associate. The deposit from which they were taken occurs as a vein a few inches thick in metamorphosed fine-grained sedimentary rocks. Chalcopyrite, pyrite and arsenopyrite were found in the same vein associated with the anthraxolite and quartz. The location of this deposit is near the intersection of longitude 112°

¹ Coleman, A. P., *Am. Jour. Sci.*, Fifth Series, Vol. **XV**, p. 27, 1928.

² Bureau of Mines of Ontario, Bulletin No. **2**, 1886.

³ *Am. Jour. Sci.*, *op. cit.*, p. 25.

with latitude 62° on the west side of Union island in the east end of Great Slave lake.

An analysis of selected fragments has been made and is tabulated below with that given by Coleman for selected material from the Sudbury district.

ANALYSES OF ANTHRAXOLITE

	(1)	(2)
Carbon.....	94.25	94.92
Hydrogen.....	1.26	0.52
Nitrogen.....	0.78	1.04
Oxygen.....	1.97	1.69
Sulphur.....	0.42	0.31
Ash.....	1.32	1.52

(1) Selected sample from Union Island. Analysis by J. A. Kelso.

(2) Selected sample from Sudbury. Analysis given by Coleman.

A proximate analysis of the same sample from Union island is given under column (1).

	(1)	(2)	(3)
Moisture.....	1.35	—	—
Volatile Matter.....	4.08	5.3	5.3
Fixed Carbon.....	93.27	64.7	74.2
Ash.....	1.30	30.0	20.5

No. (2) and No. (3) are two proximate analyses of samples from the Sudbury occurrence given by Coleman but these apparently were not made from the same sample as that used for the ultimate analysis.

The ultimate analyses of selected material from Union island and from the Sudbury district are strikingly similar and since the physical properties of both are so similar the writer is of the opinion that they are practically the same substance.

Another specimen of similar material was sent to the Department of Geology at the University of Alberta for identification a number of years ago. It came from Connor Creek, a rural district about 80 miles northwest of Edmonton, and was not suspected to be anthraxolite since this area is underlain by undeformed upper Cretaceous rocks. The specimen was set aside until more information on the geology of the district had been obtained. It is now known that there are frequent occurrences of Keewatin ice-sheet drift deposits in the Connor Creek district and apparently

this specimen is anthraxolite which has been carried to the Connor Creek district in the drift.

The general geology of the Northwest Territories of Canada has not been worked out in any appreciable detail and no correlation of the beds carrying anthraxolite at Union island with those at the Sudbury district can be attempted. The significant features of the two widely separated occurrences of anthraxolite is their similar mode of occurrence, their mineralogical associations and the fact that they occur in Precambrian rocks.

SEQUENCE OF MINERALIZATION IN THE KEYSTONE,
SOUTH DAKOTA, PEGMATITESKENNETH K. LANDES, *University of Kansas.*

CONTENTS

SUMMARY

INTRODUCTION

GENERAL GEOLOGY

Schist and slate

Granite

PEGMATITES

ETTA

HUGO

PEERLESS

INGERSOLL

MINERALIZATION

INTRODUCTION

Criteria of hydrothermal activity

Geological history of the Keystone region

Chemical considerations

PRIMARY STAGE

Minerals of the primary stage

INTERMEDIATE STAGE

Minerals of the intermediate stage

VEIN STAGE

Minerals of the vein stage

SUPERGENE STAGE

Supergene minerals

SUMMARY

The pegmatites described are the Etta, Hugo, Peerless, and Bob Ingersoll in Pennington County in western South Dakota. The deposits are pipe or dike-like intrusions into pre-Cambrian schist which forms the central part of the Black Hills uplift. Nearby, and genetically related, is the Harney Peak batholith which is itself pegmatitic. The minerals in the Keystone pegmatites were deposited in three stages. In the first stage black tourmaline, muscovite, beryl, triphylite, apatite, microcline, and quartz crystallized out from the pegmatite magma. The very abundant mineralizers were largely rejected during this mass crystallization. In the second or intermediate period they soaked through the pegmatite and replaced the older minerals with large crystals of spodumene, amblygonite, and beryl. In the third period the

hydrothermal solutions replaced earlier minerals and filled fissures, making veins. Minerals typical of this phase are albite (cleavelandite), lepidolite, yellow and green muscovite, tourmaline (indicolite), quartz, and a number of metallic minerals such as cassiterite and löllingite.

INTRODUCTION

Keystone is a small mining town located in Pennington County, South Dakota, about twenty miles southwest of Rapid City. A mail stage connects it with both Rapid City and Hill City, the latter a town ten miles to the west on the Burlington railroad. A spur runs from Hill City to Keystone, which is now used but once a week and then for freight only. Keystone is in a most rugged part of the Black Hills consequently there are no highways other than the stage routes. The town itself is surrounded by abandoned gold mines, but close by are a number of very interesting granite pegmatites. Four of these have been worked for many years and offer magnificent exposures to the visiting mineralogist. The Etta mine, long famous for its spodumene crystals, lies a mile south of Keystone. In the same vicinity are the Hugo and Peerless pegmatites which are of lesser note but of equal interest. To the northwest is the Bob Ingersoll mine which has supplied many cabinet specimens of lepidolite and columbite. The exact location of these pegmatites is given on the accompanying map. There are a number of other pegmatites in the Keystone district, but none are as well exposed.

The writer spent four weeks in this region in the summer of 1927, studying the pegmatites and making a representative collection which includes about thirty species. He is indebted to Mr. E. E. Hesnard, Superintendent of the Hugo and Peerless mines, for assistance both in the collecting of specimens and in the supplying of data which aided materially in the theoretical considerations. The writer is also grateful to his father, Prof. Henry Landes, for helpful advice in the field.

The specimens collected have been studied in the laboratory and the observations incorporated in the present paper. However, this phase of the investigation is not yet complete and it is hoped to publish a later paper giving optical, chemical, and X-ray data for a number of the more unusual minerals. The writer wishes to thank Mr. Emmett Beach of the Chemistry Department of

the University of Kansas for making analyses of several of the minerals.

GENERAL GEOLOGY

The Keystone district lies near the center of the southern Black Hills. The general geology of the Hills has been described

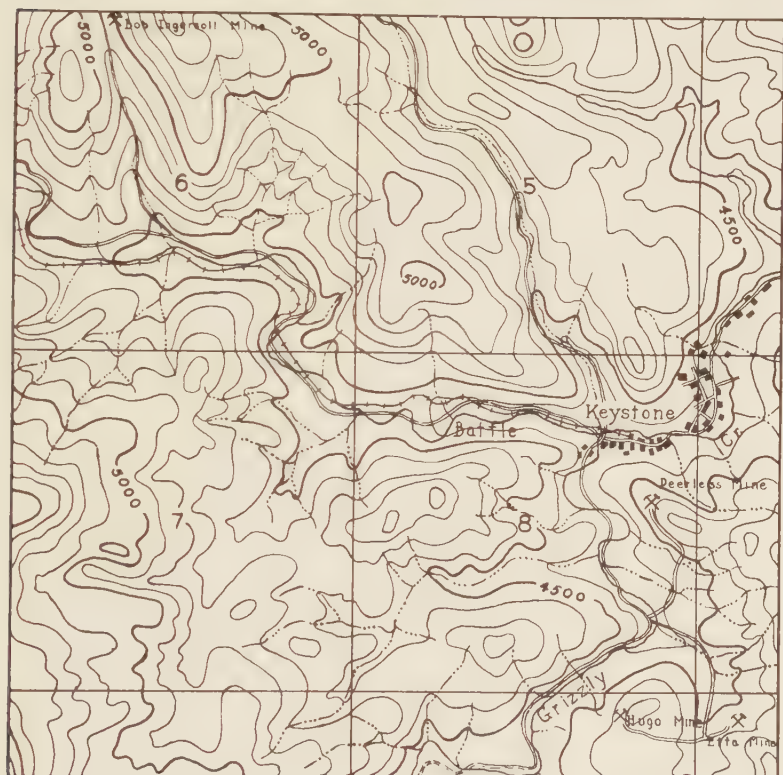


FIG. 1

Map of Keystone Area (modified after the Forest Service working plan map), T. 2S., R. 6E., Pennington County, South Dakota. Contour interval 100 ft. Sections one mile square.

by a number of writers¹ and a recent folio of the U. S. Geological Survey contains in addition to descriptive matter topographic and geologic maps of the major part of the area.² The Black Hills are

¹ O'Harra, C. C. A bibliography of the geology and mining interests of the Black Hills Region. *S. Dakota School of Mines, Bull.* 11, 1917.

² Darton, N. H. and Paige, Sidney. *U. S. Geol. Survey, Folio* 219, 1924.

erosional remnants resulting from a domical uplift at the time of the Laramide revolution. The dome is elliptical in plan with the major axis trending a little west of north. Erosion has stripped off the rocks lying across the top of the dome so that pre-Cambrian schists and granite crop out in the center and an outward dipping series of successively younger sedimentary formations, representing parts of every period from the Cambrian to the Cretaceous, except the Silurian and Devonian, are exposed between the pre-Cambrian rocks and the outer margin of the uplift. The northern Hills, where the Homestake gold mine is located, has been the scene of considerable Tertiary igneous activity. The southern Hills center in Harney Peak which has an elevation of 7242 feet. It and other peaks in the immediate vicinity are carved out of pre-Cambrian granite which is intrusive into schist. The Keystone pegmatites lie in the schist area seven miles northeast of the summit of Harney Peak, and about two miles from the nearest granite outcrop. The nearest Paleozoic rocks are over four miles eastward, so the only country rock involved in a study of these pegmatites is the pre-Cambrian.

Schist and Slate.—Schist, slate and granite form the core of the Black Hills, cropping out over an area of several hundred square miles. The plan of the general outcrop is elliptical. Ziegler³ has compiled a list of rock varieties found in the metamorphic complex in the Harney Peak region which includes actinolite, garnet, mica, staurolite, tourmaline, graphite, and quartz schists, slates, graywackes, and amphibolites. The commonest rock observed by the writer around the Keystone pegmatites was biotite schist. Newton and Jenny⁴ have described the microscopic petrography of the schists occurring to the south and southeast of Harney Peak. Van Hise⁵ notes a transition in the rocks between the margin of the pre-Cambrian and the intrusive granite. Slates lie the farthest out, but they become schists as the granite is approached and the schists in turn become coarser, more foliated, and much more crystalline immediately adjacent to the granite. Furthermore

³ Ziegler, Victor. The differentiation of a granitic magma. *Econ. Geol.*, 9, No. 3, p. 265, 1914.

⁴ Newton, Henry and Jenny, W. P. Report on the Geology and Resources of the Black Hills of Dakota. *U. S. Geog. and Geol. Survey, Rocky Mt. Region*, 1880.

⁵ Van Hise, C. R. The pre-Cambrian Rocks of the Black Hills. *Bull. Geol. Soc. Am.*, Vol. 1, pp. 203-244.

the schists in the vicinity of Harney Peak strike parallel to and dip away from the granite contact. The principal metamorphic rocks were originally sedimentary. In regard to the age Paige⁶ concludes "that the pre-Cambrian rocks of the Black Hills are probably older than Keweenawan and younger than lower Huronian and may therefore be either middle or upper Huronian."

Granite.—The Harney Peak granite is exposed in the southeastern portion of the pre-Cambrian outcrop. It produces a much more rugged topography than does the surrounding schist. The largest exposure includes Harney Peak and is about ten miles across. Many smaller outcrops occur, some of them irregular in outline while others are dike-like. These latter are especially numerous about the main granite mass. They are usually conformable to the schistosity and, therefore, strike parallel to the granite-schist contact. As the granite is approached lit-par-lit injection of dike into country rock may become so common as to obscure the actual contact. Furthermore xenoliths of schist are abundant within the granite, especially about its outer margins.

Most of the dikes are pegmatitic rather than granitic in texture, often containing quartz and feldspar individuals several feet across. Some of the rock in the larger masses is a true granite, but most of it is exceedingly coarse grained and minerals are present which are characteristic of pegmatites. On the trails ascending Harney Peak this coarse granite is well exposed. Not only are feldspar, quartz, and muscovite present in individuals measuring several inches, but also rose quartz and black tourmaline are of common occurrence. According to Paige⁷ the feldspars in the Harney Peak granite are microcline, orthoclase, albite, and oligoclase. Microcline is often combined with albite to form perthite which in turn may be intergrown graphically with quartz. Apatite, magnetite, zircon, titanite, and garnet are accessory minerals which may be observed in thin sections.

The method of emplacement of the Harney Peak granite is a problem of such magnitude that time did not permit its inclusion in the present investigation. Both Paige and Ziegler⁸ discuss this problem. Hypotheses as to the mechanics of intrusion must take into account the size of the rock body, the metamorphism and de-

⁶ *U. S. Geol. Survey, Folio 219*, p. 4.

⁷ *Op. cit.*

⁸ *Op. cit.*

formation of the country rock, the number and character of apophyses, the contact phases of the granite, and the very unusual pegmatitic character of the main mass. Ziegler believes that the granite represents the marginal zone of a batholith, probably its upper surface laid bare by erosion. Usually the margin of a batholith is of finer texture than the interior, so if this assumption is correct the Harney Peak batholith might become a truly gigantic pegmatite at depth. Paige⁹ concludes that "The relation of the rocks indicate that the granite of the Black Hills came into its present position in the main by distension of the older rock body under great pressure. The schists, deformed by the advance of the magma, were forced into closely appressed recumbent folds. The schistosity produced during this folding favored further injection by the magma through great numbers of parallel dikes and by intricate intrusion "bed by bed." The batholithic magma must have contained an unusual if not unique abundance of water and other mineralizers.

PEGMATITES

Pegmatites are found in the Black Hills in the vicinity of Harney Peak and in the Tinton district (Wyoming) at the northern end of the Hills. Probably the best known pegmatites are those lying northeast of Harney Peak, which are described in the present paper. A great number of articles have been written on these pegmatites, but most are confined to a single phase. A bibliography of the more important general articles is given below:

Blake, W. P. Tin ore veins in the Black Hills. *Trans. Am. Inst. Mining Eng.*, **13**, 691-696, 1885.

Carpenter, F. R. Notes on the geology of the Black Hills. *Trans. Am. Inst. Mining Eng.*, **17**, 588-598.

Connolly, J. P. The Etta Mine. *Black Hills Engineer*, Jan. 1925, pp. 18-23. Geology and Mineralogy of the Keystone District, *loc. cit.*, pp. 11-18.

Darton, N. H., and Paige, Sidney. Central Black Hills folio, South Dakota. *U. S. Geol. Survey, Folio* **219**.

Hess, Frank L. Tin, tungsten and tantalum deposits of South Dakota. *Min. and Sci. Press*, **100**, 822, 1910. *U. S. Geol. Survey, Bull.* **380**, 131-161, 1909. The Natural History of the Pegmatites. *Eng. and Min. Journal-Press*, **120**, No. 8, 289-298, 1925.

Lincoln, Francis Church. Pegmatite mining in the Black Hills. *Eng. and Min. Jour.*, June 18, 1927, 1003-1006.

Schwartz, G. M. Geology of the Etta spodumene mine. *Econ. Geol.*, **20**,

⁹ *Op. cit.*, page 5.

646-659, 1925. The Black Hills Mineral Region. *Am. Mineral.* Feb. 1928, 56-63.
 Sterrett, D. B. Mica deposits of South Dakota. *U. S. Geol. Survey, Bull.* 380, 382-397, 1909.

Ziegler, V. The Minerals of the Black Hills. *S. Dakota School of Mines, Bull.* 10, 1914. The differentiation of a granitic magma. *Ec. Geol.*, 9, No. 3, 264-277, 1914.
 Lithia deposits of the Black Hills. *Eng. and Min. Jour.*, 96, 1053-1056, 1913.

Pegmatite dikes have been intruded into schists on all sides of Harney Peak. Next in importance to the Keystone district is the Custer area, southwest of the peak. Several important mica deposits and the famous Scott rose quartz mine are found in this locality. The geographical relationship of the pegmatites with the Harney Peak granite forces the conclusion that the two are genetically related. They probably connect at depth. Van Hise¹⁰ notes the occurrence of dikes radiating out from the granite which near-by are granitic and farther away pegmatitic until, by a lessening of the feldspar, they grade into ordinary quartz veins.

Duncan¹¹ states that the strike of the pegmatites and the cleavage of the schists are in general parallel, but they may differ up to 40 degrees. Because the cleavage of the schist is usually parallel to the periphery of the granite the general trend of the pegmatites will be tangent to the contact. However, the Keystone pegmatites exhibit such irregularity in form (some are cylindrical) that this generalization is difficult of application. Brief descriptions of the pegmatites follow.

ETTA

The Etta pegmatite has been sporadically exploited for about 50 years. Previous to 1883 it was worked for mica. In that year cassiterite was first recognized in the deposit and extensive tin mining operations were started. These proved unsuccessful and about 1898 spodumene mining began and has continued until the present day, producing a large share of the domestic lithium. The presence in the Etta pegmatite of about sixty mineral species and the unusual size of the spodumene crystals attracted many geologists and mineralogists to the mine which resulted in the publication of a large number of papers. One of the most complete

¹⁰ Van Hise, C. R. Principles of North American pre-Cambrian geology. *U. S. Geol. Survey, 16th Annual Report, 1894-5*, p. 813.

¹¹ Duncan, G. S. Contribution to the study of the pre-Cambrian rocks of the Harney Peak district. *Trans. Am. Inst. Mining Eng.*, 43, 207-218, 1913.

of these was written by G. M. Schwartz¹² in 1925. Other recent papers have been written by Connolly¹³ and Lincoln.¹⁴ Among the older writers Blake¹⁵ deserves special mention.

The Etta pegmatite is more resistant than the schist into which it is intruded. Consequently it forms a hill or "knob" which at one time stood about 300 feet above the nearby stream valleys. The top of the knob has been removed by mining operations and a large glory hole now occupies the center. A tunnel has been driven 125 feet below the rim. The pegmatite is a nearly vertical plug, elliptical in plan, with the maximum dimensions at the level of the tunnel. The diameters here are 200 and 250 feet. The convergence above the tunnel is slight, but below the deposit pinches rapidly and diamond drilling has indicated that it closes in at 100 feet.¹⁶ In all probability it does not completely pinch out with depth, but is connected with the Harney Peak granite by a narrow feeder dike or neck.

The country rock into which the pegmatite has been intruded is a gray schist, containing quartz, biotite, muscovite, and a little garnet. Contact metamorphism has destroyed the schistosity for a short distance outward from the pegmatite creating instead a fine granular aggregate of quartz, feldspar, garnet, tourmaline, and biotite. Proceeding inward from the contact there is first encountered what Schwartz terms the "mica selvage" zone. This is from five to fifteen feet thick and consists of large quantities of muscovite with lesser amounts of quartz and feldspar. The remainder of the pegmatite consists largely of spodumene, quartz, and feldspar (microcline, microcline-perthite and albite). The spodumene crystals are very prominent on the walls of the glory hole because of their size and abundance. Some form radial aggregates while others are scattered through the mass like jackstraws. At the time of Blake,¹⁷ before mining reached its present level, four concentric zones were discernable. The outermost

¹² Geology of the Etta Spodumene Mine. *Econ. Geol.*, **20**, 646-659, 1925.

¹³ Connolly, J. P. The Etta Mine. *Black Hills Engineer*, **13**, No. 1, 18-23, 1925.

¹⁴ Lincoln, Francis Church. The Etta Mine—A Unique Lithia Producer in the Black Hills. *Eng. and Min. Jour.*, **124**, No. 6, 213-214, 1927.

¹⁵ Blake, W. P. Tin Ore in the Black Hills of South Dakota. *U. S. Geol. Surv., Mineral Resources*, 1883-4, pp. 602-613. Tin Ore Veins in the Black Hills. *Trans. Am. Inst. Min. Eng.*, **13**, 691-696, 1885.

¹⁶ Schwartz, G. M. *Loc. cit.* p. 651. Cross section on p. 653.

¹⁷ *Op. cit.*

contained both muscovite and biotite. Then came spodumene and greisen followed by a zone consisting of greisen only. The central core contained quartz with subordinate feldspar and spodumene. At the present stage of operations there seems to be little or no difference in the amount of spodumene between the mica zone and the center of the deposit. Another change which has been observed with increasing depth is a decrease in the amount of cassiterite.

HUGO

Although larger than the Etta and magnificently exposed by open cut mining operations the Hugo pegmatite has been described in detail only by Ziegler¹⁸ A briefer description was recently published by Schwartz.¹⁹ The pegmatite outcrop lies near the top of a high ridge about a third of a mile west of the Etta mine (see map). The deposit is a tabular body dipping about 79 degrees northward. It extends over 200 feet east and west and it is 650 feet from the foot wall schist northward to where the pegmatite passes under alluvium.

The country-rock adjacent to the Hugo mine is a very fine biotite schist which has been intruded for some distance from the pegmatite by thin dikes of granitic texture. Some dikes contain quartz only while others consist largely of pink feldspar with small needles of black tourmaline scattered along the contact. The dominant mineral of the schist is quartz with feldspar (orthoclase plus a little albite) and biotite subordinate. A few small grains of garnet are visible in thin section. The schist along the pegmatite contact has been metamorphosed. The quartz and feldspar have recrystallized into a coarser textured rock and varying amounts of tourmaline and muscovite have been introduced. One specimen collected from the contact apparently consisted largely of black tourmaline crystals. When sectioned and viewed under the microscope it was seen that each tourmaline crystal contained, irregularly scattered through it, many grains of quartz. All parts composing a tourmaline individual were similarly oriented (although many of these were completely

¹⁸Ziegler, V. *Lithia Deposits of the Black Hills. Eng. & Min. Jour.*, **96**, 1053-1056, 1913. Condensed and republished by Darton and Paige, *U. S. Geol. Survey, Folio 219*.

¹⁹Schwartz, G. M. *The Black Hills Mineral Region. Am. Mineralogist*, **13**, No. 2, p. 61, 1928.

isolated in the section) while no such relationship existed between the quartz grains. The latter were originally present in the schist and were incorporated by the tourmaline at the time of the pegmatite intrusion, showing the enormous crystallizing power of that mineral. Some bleaching of the biotite accompanied the recrystallization of the other minerals. The contact metamorphosed schist oxidizes to a red colored rock.

A zonal structure may also be observed within the Hugo pegmatite. Going westward from the east contact a zone of granitic textured pegmatite from three to eighteen inches thick is first encountered. Minerals present are black tourmaline, quartz, feldspar, and muscovite. Next comes a very coarse crystalline rock consisting dominantly of black tourmaline with minor amounts of microcline and quartz. This zone varies in width from six to thirty-six inches. It is followed at the east side of the deposit by the main pegmatite, but on the west side a zone containing coarse books of muscovite lies between the black tourmaline and the giant pegmatite. Ziegler²⁰ has noted the occurrence of an irregular zone of coarse granite between the mica and the main pegmatite.

In his many years of observation while superintending mining operations Mr. Hesnard has noted a crude stratification in the deposit which is conformable to the steeply dipping foot wall.²¹ Three layers occur between the lower contact and the top of the pegmatite. The first (lowest) consists mainly of muscovite and beryl. This is followed by a much thicker zone containing quartz, amblygonite, apatite, columbite, etc. The top layer consists mainly of microcline with a little quartz. At the outcrop the intermediate zone expands up into the overlying layer and contains large amounts of albite and cassiterite.

As in the usual granite pegmatite the minerals present in most abundance are quartz and microcline. The latter mineral occurs in exceptionally large masses in the top layer. In the middle zone some large nodules and shoots of amblygonite have been found, one of the latter measuring 15 by 22 by 40 feet. Spodumene is also present, in crystals which are large but not gigantic. Lepidolite, so dense as to be unrecognizable in the hand specimen, is scattered throughout the middle zone. Mining operations

²⁰ *Op. cit.*

²¹ Hessnard, E. E. Informal communication.

have uncovered a big "horse" of schist near the west side of the pegmatite.

PEERLESS

The Peerless deposit has been briefly described by Hess²² and Schwartz.²³ It is located at a considerable elevation on the spur between Battle and Grizzly Creeks, overlooking the town of Keystone. According to Hess the pegmatite is tear shaped in plan with a tail extending northwestward and a hump on the west shoulder. The areal dimensions are about 150 by 250 feet. The tail is 30 feet wide, pinching out in about 100 feet. The plunge of the deposit is to the northwest.

The country rock is a biotite schist with a small amount of tourmaline visible in the thin section. Adjacent to the contact on the southeast side of the deposit the schist is doubled over as though the intrusion had exerted pressure on the country rock and was part at least displacive. The pegmatite has at its border a zone of coarse black tourmaline. A crude stratification upward from the base has also been observed in this deposit.²⁴ The foot wall zone contains coarse books of muscovite with subordinate quartz and microcline. Then comes the intermediate layer with a motley mixture of common and rare minerals. The top zone consists of feldspar and quartz.

INGERSOLL

The Ingersoll mine is located on a group of three pegmatites situated at a high elevation two miles northwest of Keystone (see map). The country rock is a fine gray schist of varying composition. One specimen collected and sectioned was similar to the country rock at the Peerless, a biotite-tourmaline schist, except that the biotite was a little paler. In another specimen the biotite and tourmaline were very subordinate and muscovite and garnet were the important metamorphic minerals.

The pegmatites crop out on the side of a hill near the head of a small tributary of Battle Creek. The lowermost deposit is a plug which plunges about 70 degrees east, conformable to the dip of the

²² Hess, Frank L. The Natural History of the Pegmatites. *Eng. & Min. Jour.-Press*, 120, No. 8, p. 293, 1925.

²³ Schwartz, G. M. The Black Hills Mineral Region. *Am. Mineralogist*, 13, No. 2, 61-62, 1928.

²⁴ Schwartz, G. M. *Op. cit.*

schist. Its most interesting feature is a white beryl crystal nearly four feet in diameter which crops out in the face of the quarry. Other minerals present in abundance are silvery and green mica, albite (cleavelandite), quartz, black tourmaline, and thin logs of spodumene.

The middle deposit lies up the hill and about 125 feet northeast of the first. It is the smallest of the three and contains quartz, white beryl, amblygonite, microcline, albite, and both clear and yellow mica.

Pegmatite number 3 lies about 300 feet southeast of number 2 and at a slightly higher elevation. This is the largest deposit and the one containing the greatest variety of minerals. The body is nearly square in plan with the sides about 85 feet across. The dip is to the east and nearly vertical. The contact between pegmatite and hanging wall is conformable to the plane of schistosity. The foot wall is concealed by the mine dump. The outermost three to five feet of pegmatite constitutes the contact zone with large books of muscovite the most conspicuous feature. Between the mica and the actual contact there is usually (but not invariably) several inches of granitic textured rock containing quartz, microcline, muscovite, and tourmaline. At one place the first foot inward from the contact consisted of quartz crystals about four inches long and one inch in diameter growing normal to the contact plane. Within the main pegmatite a distribution of some of the more abundant minerals could be discerned, but the arrangement is extremely irregular. Near the center is a large plug of lilac lepidolite and cleavelandite. Lying between this and the hanging wall is a thick mass of milky quartz which surrounds on three sides a pipe of amblygonite. Very large crystals of microcline occupy the northeast portion of the deposit, while the remaining parts of the outcrop consist of cleavelandite, quartz, lepidolite, indicolite, columbite, etc.

(To be continued)

NOTES AND NEWS

TOURMALINE—BEARING QUARTZ FROM AMELIA, VIRGINIA

GERALD R. MACCARTHY, *University of North Carolina.*

On a recent collecting-trip several large quartz crystals were obtained from an abandoned prospect pit which had been opened a few years ago on the outcrop of one of the famous Amelia (formerly known as Amelia Courthouse) pegmatites. These crystals were of typical, although rather light colored, smoky quartz. The largest weighed about five pounds. When cleaned of the adhering clay they seemed to be rather good specimens of "rutilated quartz," and as such were shipped to the laboratory.

A more detailed examination under the binoculars disclosed the fact that the numerous hair-like inclusions were darker than is the usual case, being a brownish black rather than the red-brown of ordinary rutile. A fragment filled with a net work of these inclusions was broken from the base of one of the crystals and tested for titanium with entirely negative results.

A further search revealed several small acicular crystals of what appeared to be black tourmaline, although they were too small for close examination. When tested these needles reacted strongly for boron. A similar test was then run on several portions of the more typical "rutilated" material, decisive tests being obtained in every case. Evidently all of the "rutile" was tourmaline.

Since these crystals simulated so perfectly the appearance of rutilated quartz, the question arises; may not some of the specimens in our museums and laboratories now labelled "Rutilated Quartz" be in reality "tourmalinated" rather than "rutilated?"

The use of andalusite (and more recently of andalusite and dumortierite) in the manufacture of porcelain for spark plugs has been frequently recorded in the literature. These same minerals are now being used in the manufacture of what commercially is known as "sillimanite" laboratory ware, including beakers, casseroles, combustion tubes, crucibles, evaporating dishes, funnels, etc. Some of the advantages of the "sillimanite" ware over ordinary chemical porcelain are its higher thermal conductivity, thus shortening the time required for evaporation, and its much greater resistance to shock, reducing breakage about 25 to 30 per cent.

Dr. Robert B. Sosman has resigned from the Geophysical Laboratory of the Carnegie Institution of Washington and has accepted a position in the recently established research laboratory of the United States Steel Corporation at Kearny, New Jersey.

Professor John T. Lonsdale of the Bureau of Economic Geology, University of Texas, has accepted the position as head of the department of geology at the Agricultural and Mechanical College of Texas.

Professor E. Wiechert, director of the Geophysical Institute and professor at the University of Göttingen, recently died, aged sixty-seven years.

Dr. Andrew C. Lawson, professor of geology and at one time dean of the College of Mining of the University of California, retired in July, after thirty-eight years of service on the faculty. He becomes emeritus professor of geology and mineralogy.

REVIEWS

ELEMENTS OF OPTICAL MINERALOGY—AN INTRODUCTION TO MICROSCOPIC PETROGRAPHY. ALEXANDER N. WINCHELL. Third edition, revised and enlarged. PART 1. PRINCIPLES AND METHODS, IV+238 pages with 260 illustrations. John Wiley & Sons, Inc., New York, 1928. Price \$3.50.

The second edition of this popular text on optical mineralogy appeared in 1922. (Reviewed in *Am. Mineral.*, vol. 8, p. 36, 1923). In the third edition an additional chapter of 22 pages has been added on "Special Methods of Study." In this chapter the applications of the universal stage of Fedoroff, and the dispersion methods of immersion liquids for the accurate determination of the optical properties of crystallized material, are described in considerable detail.

In the single dispersion method by varying the temperature of the liquid its index can be made to coincide with that of the mineral. In the double dispersion method the index of the liquid is altered by a change in temperature and in the wave length of the light used. By the dispersion methods, under favorable conditions, it is possible to attain an accuracy of $\pm .001$. A complete discussion of these methods and the liquids used will be found on page 504 of this issue.

W. F. H.

ON THE MINERAL DUMORTIERITE. BULLETIN BY THE MACKAY SCHOOL OF MINES STAFF, UNIVERSITY OF NEVADA. *Bull.* 2, Vol. 22, 1928.

This bulletin of 47 pages contains short articles by four members of the School of Mines staff, each contributing that portion which falls in his special field of interest. The mineralogy of dumortierite including the bibliography (consisting of 53 titles) was compiled by O. R. Grawe; the geology of the deposit in Humboldt Queen Canyon, Pershing Co., Nevada, its origin and petrography were written by J. C. Jones; the mining of dumortierite is described by J. A. Carpenter; while W. S. Palmer recorded the dressing tests.

While dumortierite has been reported from seven States in the Union, the Humboldt Queen deposit is, thus far, the only commercial occurrence of this mineral in the world. Here it occurs in lenticular masses and in quartz veins, the former originating through the replacement of pre-existing lenses of andalusite formed in an earlier stage in the metamorphism of the rocks.

The use of this mineral, together with that of andalusite, in the manufacture of spark plug porcelain and special chemical porcelain ware is briefly described. This bulletin is the first of a series to be issued on "live subjects of interest to the industry."

W. F. H.